Physiological Effects of Electrical Shock
V2 9019-21, 23
Overview

Overview

Physiological Current Limits

Executive Summary

Provides parent standard for nominal electrical isolation & grounding requirements
Provides catastrophic limits for failures – hazard analysis
Provides guidance on body impedance to calculate associated voltages
Based on Electrotechnical Commission (IEC) Documents

For spaceflight applications it is important to protect humans from unintended electrical current flow. These standards define the physiological limits for current flow for the following situations:

- *Nominal – Under all situations*
- *Catastrophic hazard threshold for all conditions*
- *Catastrophic Hazard threshold specifically for Startle Reaction*
- *Leakage Current* Designed for Human Contact

Current threshold were chosen (vs. voltage thresholds) because body impedance varies depending on conditions such as wet/dry, AC/DC, voltage level, large/small contact area but current thresholds and physiological effect do not change. By providing the electrical thresholds, engineering teams are able to provide the appropriate hazard controls usually provide additional isolation (beyond the body's impedance), providing current limiters and/or modifying the voltage levels.

"Catastrophic hazard" language was used to relate the physiological level that shall not be exceeded without additional controls.

Below is a summary of the electrical current thresholds:

	Nominal Perception Current Thresholds [V2 9019]	Leakage Currents – Equipment Designed for Human Contact [V2 9023]	Catastrophic Physiological **Startle** Reaction Current [V2 9021]	Catastrophic Physiological Threshold Current **For all situations** [V2 9020]
DC Limits	0.4 mA	0.1 mA	2.0 mA	40 mA
AC Limits	0.2 mA	0.1 mA	0.5 mA	8 mA

Body Impedance

Guidance is provided in order to determine the appropriate body impedance for calculating the associate voltage with a given current threshold.

Background

Physiological Current Limits

Data/evidence to determine the physiological thresholds are from International Electrotechnical Commission (IEC) documents along with associated rationale are as follows:

- *Nominal – Under all situations These values are below the physiological effect of sensation for the most sensitive members of the astronaut population. This requirement is intended to address typical exposure situations where human contact can routinely occur with conductive housing of electrical equipment and in these situations no perceptible current flow is the design requirement. Typically NASA engineering teams establish 1 MΩ isolation along with grounding to conductive surfaces with Class H or better bond to prevent current flow through crew members*

- *Catastrophic hazard threshold -These thresholds are used when a hazard analysis is considering failure scenarios and off nominal events where failures such as electrical short circuits have compromised system isolation and pose a risk of catastrophic electrical shock to the human*

    - *Catastrophic hazard threshold for all conditions -The current values were chosen based on the threshold for maintaining muscle control if shocked to protect 99.5% of the population (IEC TR 60479-2, Figure 7). This standard is intended to provide the threshold where additional engineering controls will be required to mitigate electrical shock/physiological effects to the human.*
    - *Catastrophic Hazard threshold specifically for Startle Reaction - The current values were chosen based on the threshold for a startle reaction if shocked (IEC TR 60479-5, Table 1). Under certain circumstances such as startle reaction, more restrictive thresholds than the physiological catastrophic limits of the [V2 9020] limits above shall be employed in hazard and risk assessments*

- *Leakage Current* Designed for Human Contact - *These levels of leakage current are consistent with those in IEC 60601-1, Medical Electrical Equipment–Part 1*

***Body Impedance Guidance** – In order to determine appropriate voltage levels not to exceed the current thresholds the following guidance is provided: utilize 5th percentile values for the appropriate conditions (wet/dry, AC/DC, voltage level, large/small contact area) from IEC TR6049-1 to determine the appropriate body impedance to calculate the voltage associated with any current limit analysis.*

Reference Data

Data From IEC documents were utilized to set current thresholds.

[V2 9020] Catastrophic hazard threshold for all conditions.

The current values were chosen based on the threshold for maintaining muscle control if shocked to protect 99.5% of the population (IEC TR 60479-2, Figure 7). The DC component is the x-axis (red arrow) and the peak AC component is the y-axis (yellow arrow). The 99.5th percentile for the most sensitive population (women) was chosen.

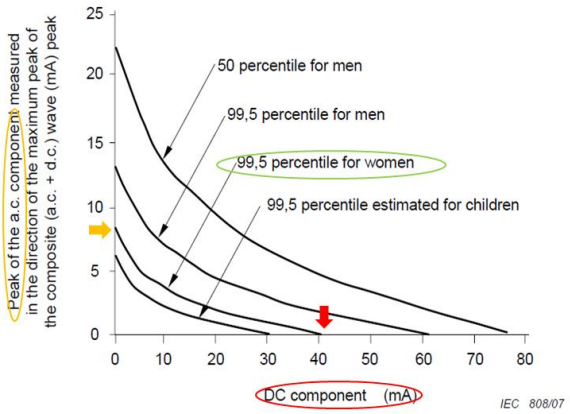

Figure 7 – Let-go thresholds for men, women and children

(IEC) *TR 60479-2, Figure 7.*

[V2 9021] Catastrophic Physiological Electrical Current Limits for Startle Reaction

[V2 9021] Startle Response is defined as a current level flowing through the body that is just enough to cause involuntary muscular contraction

The current values were chosen based on the threshold for a startle reaction if shocked (IEC TR 60479-5, Table 1).

Table 1 – Current threshold values for each condition and for long duration

Type of threshold	Current	Current path	mA
Current of startle reaction	a.c.	Hand-to-hand	0,5
		Both-hands-to-feet	0,5
		One-hand-to-seat	0,5
	d.c.	Hand-to-hand	2
		Both-hands-to-feet	2
		One-hand-to-seat	2
Strong muscular reactions	a.c.	Hand-to-hand	5
		Both-hands-to-feet (Note 1)	10
		One-hand-to-seat	5
	d.c.	Hand-to-hand	25
		Both-hands-to-feet	25
		One-hand-to-seat	25
Ventricular fibrillation (Note 3)	a.c.	Hand-to-hand	100
		Both-hands-to-feet	40

IEC TR 60479-5, Table 1

Reference Documents

Electrotechnical Commission (IEC) Documents

IEC TR 60479-1, Effects of current on human beings and livestock – Part 1: General aspects, 4th edition, 7/2007

IEC TR 60479-2, Effects of current on human beings and livestock – Part 2: Special aspects, 3rd edition, 5/2007

IEC TR 60479-5, Effects of current on human beings and livestock – Part 5: Touch voltage threshold values for physiological effects, Edition 1.0, 11/2007

IEC 60601-1, Medical Electrical Equipment–Part 1, Edition 3.1, 10/2013

Application Notes

Standard Utilization Guidance

The electrical shock standards were written to: (1) provide parent standard for engineering requirement to limit current flow in routine operations (V2 9019 and 9026) and (2) Provide information for use in determining severity of hazards in all failure/off-nominal situations V2 9020 and for unique situations such as protecting for a startle reaction V2 9021. See below.

Nominal Operations	V2 9019 is the parent standard that ensure adequate isolation is maintained through the vehicle/operations for routine	V2 9023 is the parent standard that ensure adequate isolation is for devices in contact with the human body
Hazard Analysis	Catastrophic Physiological Electrical Current Limits V2 9020 is the limit that shall not be exceeded under all failure/off-nominal conditions	Catastrophic Physiological Electrical Current Limits for Startle Reaction V2 9020 is a lower limit that shall be used for unique situation where a startle reaction may be catastrophic

Body Impedance Guidance

In many instances application of these standards will require the determination of the appropriate body impedance for the calculation of voltage. V2 9022 requires that the 5th percentile is selected in order to protect 95% of the population.

- *To calculate the appropriate voltage not to exceed the electrical thresholds, the proper body impedance must be selected. Factors that must be considered are the condition of the human/environment wet vs. dry, AC/DC, voltage level, large/small contact area.*

- *An Example utilizing IEC TR 60479-1, Table 3, 850 Ω represents the 5th percentile of the population for a touch voltage of 125 volts and a large contact area (such as full hand or a surface area of 82 cm²) in saltwater-wet conditions. (Note Table 10 of IEC 607479-1 may be used for dry conditions.) For a catastrophic hazard analysis, V2 9020, the not to exceed voltage would be*

  V_{DC} *threshold* = 850 Ω x 40 ma = 34 V_{DC}

TS 60479-1 © IEC:2005 – 35 –

Table 3 – Total body impedances Z_T for a current path hand to hand a.c. 50/60 Hz, for large surface areas of contact in saltwater-wet conditions

Touch voltage V	Values for the total body impedances Z_T (Ω) that are not exceeded for		
	5 % of the population	50 % of the population	95 % of the population
25	960	1 300	1 755
50	940	1 275	1 720
75	920	1 250	1 685
100	880	1 225	1 655
125	850	1 200	1 620
150	830	1 180	1 590
175	810	1 155	1 560
200	790	1 135	1 530
225	770	1 115	1 505
400	700	950	1 275
500	625	850	1 150
700	575	775	1 050
1 000	575	775	1 050
Asymptotic value = internal impedance	575	775	1 050

NOTE 1 Some measurements indicate that the total body impedance for the current path hand to foot is somewhat lower than for a current path hand to hand (10 % to 30 %).

NOTE 2 Due to low skin impedances in this case it may be assumed that Z_T depends little on the duration of current flow; Z_T approaches the internal body impedance Z_i.

NOTE 3 For the standard value of the voltage 230 V (network-system 3N – 230/400 V) it may be assumed that the values of the total body impedance are the same as for a touch voltage of 225 V.

NOTE 4 Values of Z_T are rounded to 5 Ω.